ECL 254

A GRATE PROBLEM

A study of a bicycle accident which resulted from the front bicycle wheel dropping into a drainage grate. The rider, who suffered severe facial injuries, entered suit against the city seeking damages. The study was done to determine if the drainage grate constituted a hazardous condition in the roadway.

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Part A: A Bicycle Accident

George Black was a 33-year old civil engineering professor at a state university located within a middle-sized midwestern city. George's primary interests were teaching transportation engineering courses and conducting research in urban transportation planning. But, he would also do some consulting work on projects that he thought were important and needed his expertise. On a Monday afternoon, one of the midwest's finest fall days in 1979, George received a call from Tom Wilson, a young lawyer who had a practice located downtown. Tom explained to George that one of his clients, Sue Ellen Porch, had initiated a lawsuit against the city claiming that a hazardous drainage grate placed in the roadway caused her to have a bicycle accident which resulted in severe injuries to her face and jaw. Tom said that he would like to have a traffic engineering expert conduct an investigation of the accident. He said that one of George's colleagues recommended George to him, and that he would like George to conduct the investigation.

"Well, Tom, I have a heavy schedule for the next month and I don't know if I can work on the project. When did you need the work done?"

"No rush, George. It doesn't have to be done in the next week."

"I'd like to think it over and call you back tomorrow morning if that is all right with you, Tom."

"Fine. I'll talk to you tomorrow."

Since George had once been involved in the planning of bicycle facilities, he knew that drainage grates were often extremely hazardous to bicyclists, and he also knew that city officials often ignored these grates even when bicyclists repeatedly pointed out their hazards. George felt that he could make a contribution in verifying that certain grates were dangerous to bicyclists, and he hoped that this law case would eventually lead to a widespread correction of the problem within the city. The next morning, he called Tom.

"Tom, I would like to work on this case with you. I believe this is an important problem that needs attention."

"Good. I am glad that you decided to take the case. Now, we need to set up a meeting to give you background on the accident."

"How about next Friday afternoon at 1:00 PM?"

"That will fit into my calendar. See you then."

Next Friday afternoon, George went downtown to meet with Tom to find out the facts of the case. After getting a cup of coffee, Tom explained the case to George.

The bicycle accident occurred about 4:00 PM, September 26, 1977, a clear moderate day, on 100th Street. Sue Ellen was stopped at a red light in a westbound lane of Blake Street. After the signal turned green, she followed an automobile in front of her through the intersection making the left turn to southbound 100th Street. Sue Ellen claimed that the vehicle behind her was "right on her tail," and this caused her to pedal her bike between 25 and 30 MPH. At the time, 100th Street was being reconstructed to a four-lane divided roadway and southbound 100th Street was narrowed to one travel lane between the construction area and the curb (See Figure A-1). Sue Ellen proceeded southbound on the roadway pedalling as fast as she could. The automobile behind her was still on her tail and this caused her to move to the right side of the roadway. As she moved to the right, she drove into a drainage grate placed on the roadway surface which extended from the curb into southbound 100th Street. The front wheel of her bicycle dropped into one of the openings of the drainage grate, her bicycle came to an abrupt stop, and she went head over heels over the handle bars. Her face was severely cut and her jaw was broken. The driver of the automobile following Sue Ellen kept on going and didn't bother to help Sue Ellen.

Tom then showed George photographs he had taken of the scene of the accident including pictures of the drainage grate. Actually, two grates were placed back to back in the roadway extending approximately four to five feet into the roadway.

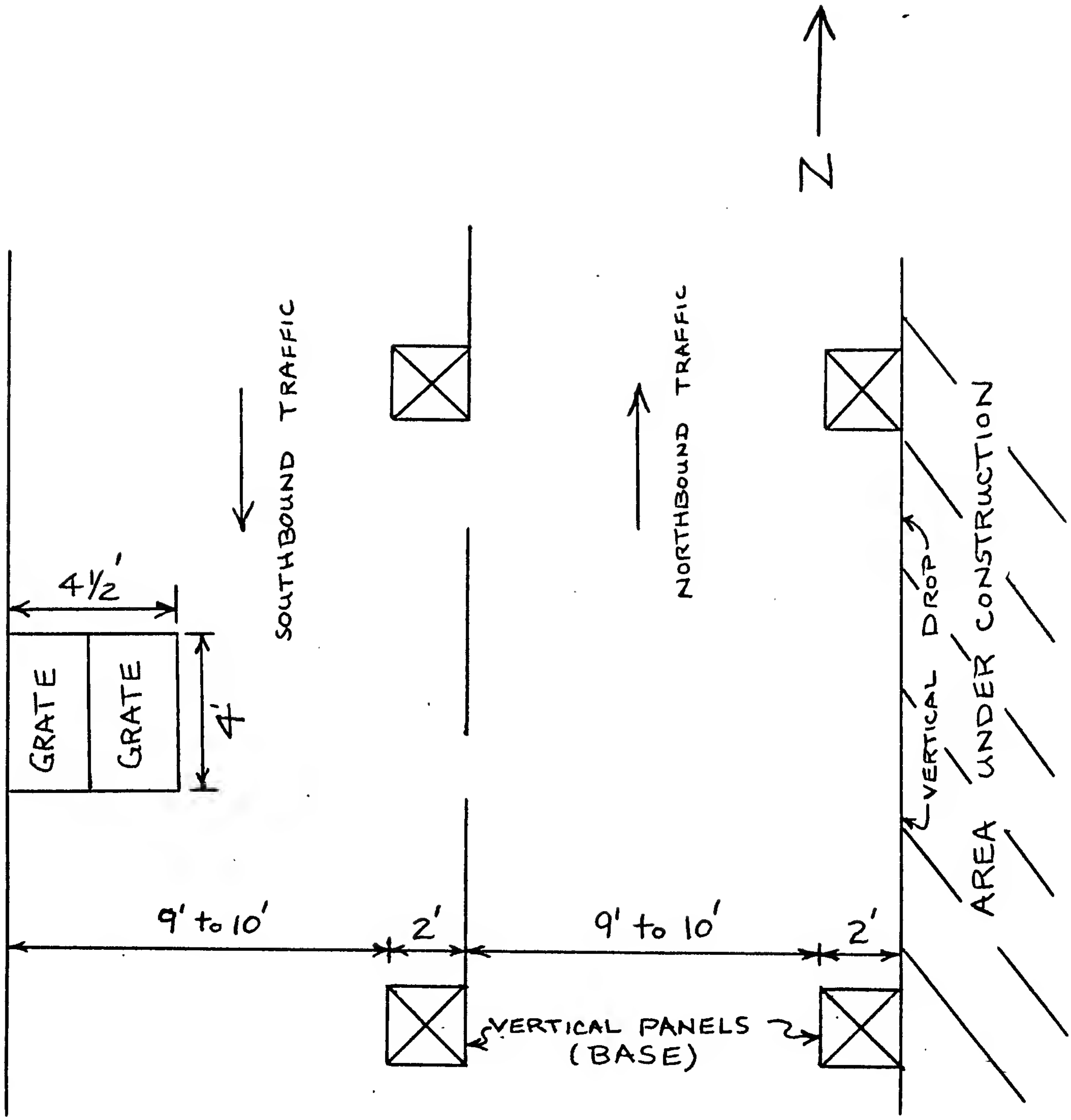
"Can I go out and look at these grates in place today?"

"No, George. Everything out there has changed due to the construction. But, the city, at my request, is storing the two grates in one of its maintenance sheds. We can go down there at your convenience."

"Well, how would you like to proceed, Tom?"

If you were Tom Wilson, what would you reply?

If you were George Black and Tom Wilson asked what you would suggest, how would you answer?



NOTE: ALL DIMENSIONS ARE APPROXIMATE

Figure A-1. Accident Area (100th St.)

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Part B: Setting Direction

Tom has given George a general description of Sue Ellen's accident. He now turned to what he thought was the basis for his lawsuit against the city.

"I would like to prove that this grate is a hazard and that the city was negligent in not replacing the grate with a safer one. We should concentrate on showing that the grate does not conform to a safe, standard design."

"The problem is, Tom, that in some preliminary research I did for this meeting, a common standard, safe design does not appear to exist. The literature that was available to me mentions that parallel-bar grates can be a hazard to bicyclists, but they do not mention standard safe designs."

"That's too bad. I was hoping that a common standard design was recommended by a state or federal agency and that we could prove the city was negligent in not applying the standard."

"That won't be easy to do. But, I think that we can show that the problem of parallel-bar grates is well documented and that various agencies throughout the nation have taken action to correct this problem."

"If that is the case, we can demonstrate that professionals in the city should have been aware of the problem and taken action to replace this type of grate."

"Yes, I believe we can show this."

Both men agreed that the first step was for George to review the literature in more detail in order to determine if this type of drainage grate is in fact a hazard to bicyclists. Tom believed that this case depended on whether or not this grate was a hazard and wanted to concentrate on this point before examining the other facts of the accident.

George said goodbye to Tom and told him that he would be in contact after he had gathered some more information.

During the next couple of days George worked in the University library to review books and documents with regard to the dangers of parallel bar grates.

What type of information would you look for if you were George Black?

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Part C: Getting A Handle On The Problem

George discovered that the dangers of parallel-bar sewer grates to bicyclists have been well documented in the technical literature over the past decade. David Whitman of the Center for Automobile Safety published a comprehensive review of the problem in 1974 (1). He documented two fatalities and 11 serious injuries attributed to parallel-bar grates. According to Whitman, many agencies throughout the nation took action to correct problems with parallel-bar grates. For example, the Michigan State Department of Highways revised design catalogues to contain hydraulically efficient, bicycle-safe "sinusoidal" grates (See Figure C-1). The Pennsylvania Department of Highways discontinued the use of parallel-bar grates and changed to hydraulically efficient grates with diagonal slots. Michigan and California banned the production of parallel-bar grates. In fact, a California law requires that grates on state highways, county highways, and city streets constructed in the future not be hazardous to bicycles (2, p. 172). The Missouri Highway Department installed crossbars on over 7,200 parallel-bar grates in St. Louis, Missouri, and surrounding suburbs. The City of Parma, Ohio, installed crossbars at more than 1,000 locations where parallel-bar grates were present. The District of Columbia Department of Highways corrected numerous grates and painted them yellow and erected warning signs. Similar actions were taken by other municipalities and states to minimize the potential hazards of parallel-bar grates.

The use of parallel-bar grates was popularized during the 1950's and early 1960's largely by the Bureau of Public Roads (now Federal Highway Administration (FHWA)). At this time, engineering judgment was that parallel-bar grates were superior to other types of grate inlets with respect to hydraulic capacity. But the Hydraulic Engineering Circular No. 12 stated: "Choice of inlet cannot always be made upon capacity alone (3, p.12-22)." The report continued: "Grates with bars parallel to the flow, while much more efficient hydraulically, may be hazardous to bicyclists if spacing between bars is wide (3,p.12-22)." The circular also presented a parallel-bar grate standard used by the California Division of Highways. This standard presented alternate grates having varying drainage opening spacing. The Type 24-18 grate had a 3/4 inch spacing and the note to the standard stated: "Use within the roadbed under urban conditions where bicycles and pedestrians are permitted (3, p.12-56)." Thus, a 3/4 inch width was recommended for areas with bicycles rather than 1-3/8 inch or wider spacing.

As bicycling became more popular in the early 1970's, government agencies became more cognizant of the parallel-bar grate problem: Reports by the Federal Highway Administration and the American Association of State Highway and Transportation Officials have emphasized the problems with parallel-bar grates and suggested improvements (4, p. 82; 5, pp 24-25). Early in 1970, the FHWA also initiated a project to investigate the hydraulic characteristics of bicycle-safe grates (6). For this study, grates with transverse spacing up to six inches were considered to be tolerable by bicyclists. Given this spacing, a 20-inch bicycle wheel

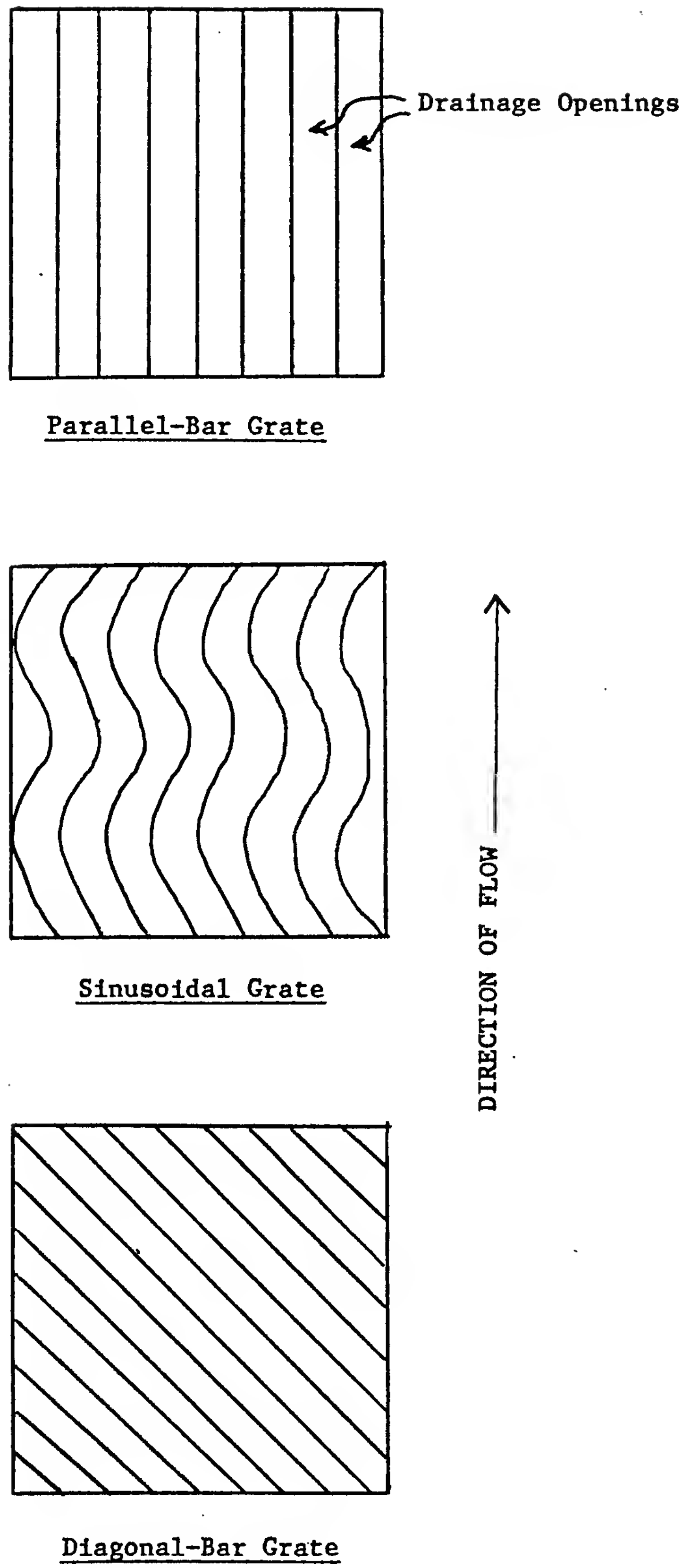

Figure C-1. Alternate Drainage Grates

would drop approximately 1/2 inch into the drainage opening. The results of the hydraulic tests on the bicycle-grates were encouraging and further study was recommended.

Another study of both the safety and hydraulic characteristics of alternate grate designs was sponsored by the FHWA in mid-1970 (7). A detailed bicycle safety study was conducted in September and October 1975 to determine the performance of sewer grates in relation to bicycle and pedestrian safety. The following criteria were measured: (1) swerves; (2) skidding; (3) speed retardation; (4) comfort; (5) ability to recognize grates as safe to ride across; (6) effect of grate on steering control; (7) grade-induced skidding; and (8) tire deformation. Based on the results of the safety test, the report noted: "All of the grates tested are markedly safer than many of the parallel-bar grates in common use today (7, p. 3-13)." In general, grates with transverse spacings over four inches performed poorly with respect to safety. Also, the results of the hydraulic tests on the bicycle-safe grates were favorable.

George was convinced that parallel-bar grates are a danger to bicyclists. He now needed to examine the hydraulic grates which had been stored by the city. He called Tom to set up an appointment for both of them to look at the grates.

Before going out to examine the grates, George removed the 27 x 1-1/4 inch wheel from his own bike. He wanted to measure how far the wheel would drop into the drainage openings of the grates.

Each grate measured approximately 4 feet long by 2 feet wide and was divided into two sections by a 1-1/8 inch wide transverse bar. Each section then had ten drainage openings approximately 21-1/2 inches long by 1-3/8 inches wide. The drainage openings were separated by longitudinal bars approximately 7/8 of an inch wide. A 27 x 1-1/4 inch bicycle wheel dropped 5-1/2 inches into the opening placing the hub 8 inches above the sewer grate. The wheel was placed in several different openings to make sure that one opening was not unusually different in width than the other openings.

George was positive that a bicycle rider would be thrown over the handle bars if his front wheel dropped over 5 inches into the drainage openings. But, he did not find any specific data as to how far a wheel could drop and the bicycle could continue over the grate. George wanted to be able to state that a bicyclist would go head over heels over the handle bar if his front wheel dropped 5-1/2 inches. He then sat down to think of ways he could demonstrate this fact.

If you were George Black, how would you proceed so that you could convince a jury of "average" people?

Part C: References

1. Whitman, David. "Dangers of Parallel-Bar Sewer Grates." Proceedings of the Seminar on Bicycle/Pedestrian Planning and Design. Metropolitan Association of Urban Designers and Environmental Planners. New York: American Society of Civil Engineers. 1974.

2. U. S. Department of Transportation. Traffic Laws Commentary: Bicycling Laws in the United States. Washington, D. C. September 1974.

3. U. S. Department of Transportation. Drainage of Highway Pavements. Hydraulic Engineering Circular No. 12. Washington, D.C. March 1969.

4. Federal Highway Administration. Bikeways: State-of-the-Art 1974. FHWA-RD-74-56. Washington, D. C. 1974.

5. American Association of State Highway and Transportation Officials. Guide For Bicycle Routes. Washington, D.C. 1974.

6. Federal Highway Administration. Hydraulic Characteristics of Two Bicycle-Safe Grate Inlet Designs. FHWA-RD-74-77. Washington, D.C. November 1974.

7. Burgi, P.H. and Gober, D.E. Bicycle-Safe Grate Inlets Study. Volume 1. Hydraulic and Safety Characteristics of Selected Grate Inlets on Continuous Grades. Prepared for the Federal Highway Administration. FHWA-RD-77-24. Washington, D.C. June 1977.

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Part D: Computing the Safe Drop

George decided to analyze the problem mathematically. He was not about to don a helmet and go around running over various grates. Since Sue Ellen took a spill over the handle bars ("a header"), he would calculate the maximum height a bicycle wheel could drop without the rider taking a header over the handle bars.

After reviewing some literature on the mechanics of bicycling (1,2), George decided to first approach the problem as a bicycle rolling over a fixed object. He then sketched the force diagram for a bicycle impacting a fixed object (Figure D-1). As the wheel impacts an object (point 2), there is a reaction R_2 which is perpendicular to the wheel and which passes through the hub (neglecting friction at the hub). There is an equal but opposite force, R, which is the resultant of the inertia force, F, and the combined weight, W, of the system (bicycle and rider).[1] This resultant passes through the center of gravity, CG, of the system. Thus, a couple, Rd, exists which causes the CG to pivot about the point of impact (point 2). If the rider does not propel himself over the obstruction at the time of impact with a torque equal to or greater than Rd, he will take a header.[2]

If there is no couple causing the CG to pivot, then the rider will not take a header. If R and R_3 act along the same line, then no couple exists about point 3. Since R_3 passes through the hub and R passes through the CG, both forces must pass through the hub and CG to be on the same line of action. Therefore, a straight line connecting the CG through the hub (point 1) will define point 3 at which the wheel can impact without the rider taking a header.

George located the CG using horizontal and vertical distances recommended in one of his references (2,p.159). He then computed the height of the fixed object, h, by proportional triangles to be approximately three inches.

George concluded that a 27-inch bicycle can safely roll over a three-inch fixed object without the rider taking a header. But, this condition represents a better condition than a bicycle wheel dropping into a drainage opening. As the wheel drops into the opening, the CG of the system shifts forward and downward. In order to compute the new CG, George assumed that the CG remained perpendicular to the bicycle frame as the front wheel dropped. Using a scaled sketch (Figure D-2), George estimated that the drop, h, could be approximately 2" before the

[1]For a discussion of inertia-force vectors see Reference 3, pp 76-77.

[2]George believed that it was a sound assumption that Sue Ellen did not purposefully propel herself over the grate.

rider would take a header. Therefore, a 5-1/2" drop would definitely cause the new CG to pivot about the point of impact.

George now felt that he could safely state that a 5-1/2" drop into the drainage grate would cause the rider to take a header. Clearly, the hydraulic grate involved in this accident was a hazard to bicyclists. He called Tom to set up a meeting to explain his findings to him.

In your capacity as a traffic safety engineer, how do you react to George Black's analysis? Can you constructively criticize his analysis? Can you make a better analysis (use your own definition of better)?

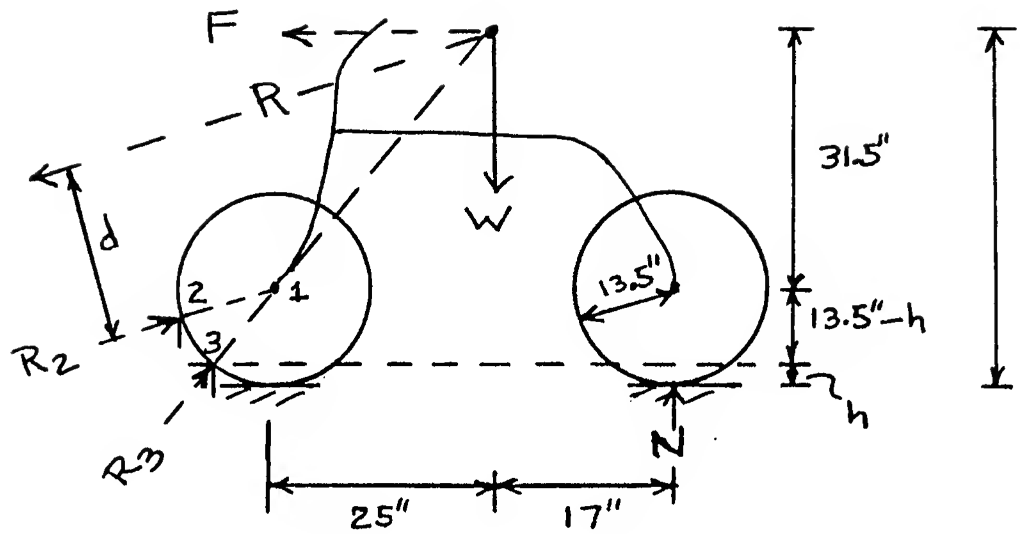

Figure D-1. Force Diagram

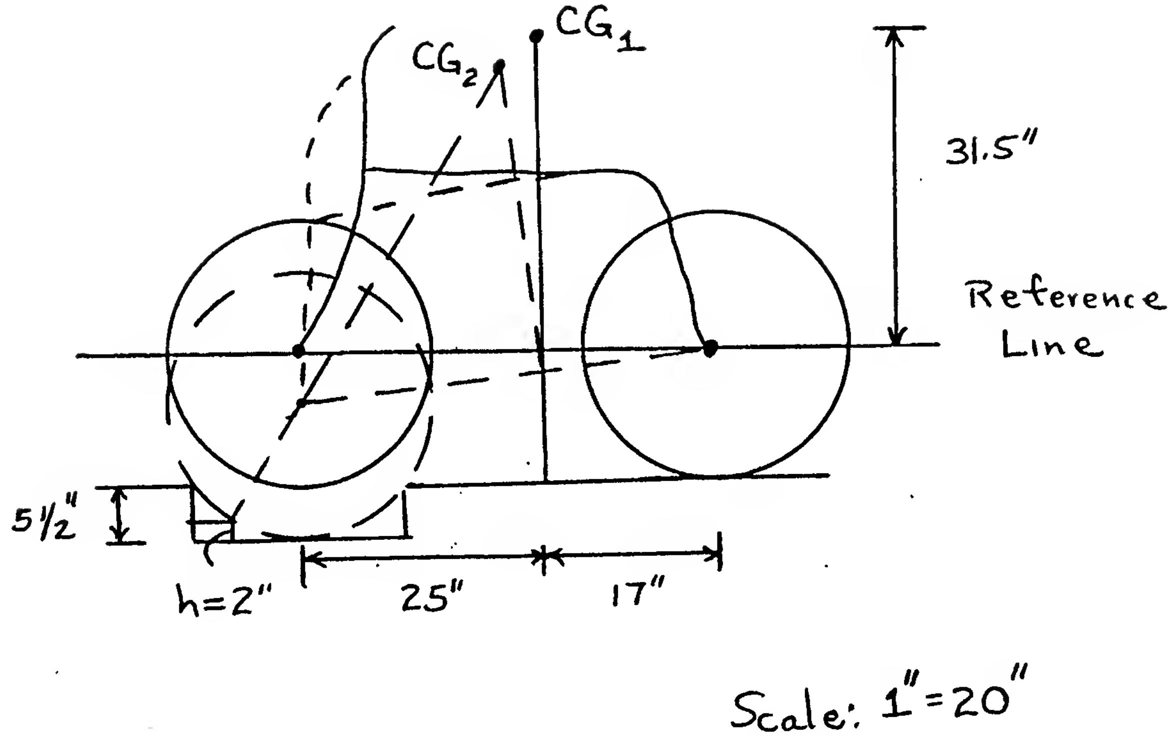

Figure D-2. Finding the Drop

Part D: References

1. Sharp, Archibald. Bicycles and Tricycles. Reprint of 1896 edition. Cambridge: The MIT Press. 1977.

2. Whitt, F. R. and Gordon, David W. Bicycling Science Ergonomics and Mechanics. Cambridge: The MIT Press. 1974.

3. Hibbeler, R. C. Engineering Mechanics: Dynamics. 2nd Edition. New York: Macmillan Publishing Co., Inc. 1978.

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Part E: Prologue

After George reported his findings, Tom asked him to prepare a report to be submitted to the city. Tom thought that a report might encourage the city to settle the suit out of court. The report was prepared and submitted to the city, but at the time of this writing no settlement has been reached.